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Assessment of COSMO-CLM performances over Mediterranean Area

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SUMMARY In this paper, the capabilities of COSMO CLM on simulating the main features of the observed climate over the whole Mediterranean area have been analyzed. The investigated period is 1971-2000. A simulation driven by ERA40 Reanalysis has been performed at a spatial resolution of 14 km in order to provide an assessment of regional model performance on local scale for impact studies. 2-metres mean temperature and total precipitation simulated values have been compared with E-OBS observational dataset; moreover, the total cloud cover has been validated with respect to the ERA-Interim Reanalysis.

1 - INTRODUCTION

The Mediterranean area is situated between Northern Europe and African Continent (two heavily different regions, by climate terms), so its peculiar position determines a complex whole of conditions and features, that makes them a worthy subject to analyze and, possibly, predict. It is connected to the Atlantic Ocean by the shallow Strait of Gibraltar and is composed of two basins of similar size, i.e. the Western and the Eastern Mediterranean Seas, separated by the shallow and narrow Strait of Sicily. To the northeast it is also connected to the Black Sea through the Bosporus channel. In the Strait of Gibraltar, at the surface, the comparatively fresher Atlantic water flows into the Mediterranean Sea to replace both the evaporated water and the denser, saltier Mediterranean water flowing out at depth into the Atlantic. The circulation is characterized by the presence of sub-basin gyres, intense mesoscale variability and a strong seasonal signal. Interannual variability is also observed and is directly related to interannual variability of atmospheric forcings (Josey, 2003 [10]). Such physical processes have two critical characteristics: first, they derive from strong air-sea coupling and, second, they occur at fine spatial scales. Any minor change occurring in this circulation system (e.g. shifts in the location of mid-latitude storm tracks or sub-tropical high pressure cells) may trigger considerable alterations of Mediterranean climate (Giorgi and Lionello, 2008 [7]): for such reason, also increasing concentrations of greenhouse gases deserve a particular attention (e.g. Lionello et al., 2006a; Ulbrich et al., 2006). Under these conditions, Mediterranean area is considered a great point of interest - also defined "hot spot" - for future climate change projections (Giorgi 2006 [5]). Given its semi-enclosed nature, as well as its smaller thermal inertia compared to large oceans, this sea is more sensitive to variations in atmosphere-ocean interactions. It is uncertain how projected climate change will cause further modifications within the marine ecosystem, breaking existing food chains and modifying ecological balances and ocean productivity, so the first step to understand the observed changes in ecosystems is the evaluation of the environmental status of the basin.

The climate of the landlocked Black Sea can be characterized generally as continental (i.e., subject to pronounced seasonal temperature variations), although climatic conditions in some parts of the basin are controlled to a great extent by the shoreline relief. A steppe climate, with cold winters and hot, dry summers, is found in the northwestern part of the basin exposed to the influence of air masses from the north. The number of available Black Sea dataset is growing permanently, however this process is still rather slow and insufficient (Vladimyrov 1999 [17])) and so it is difficult to validate the performances of climate models over this area.

Two types of modelling tools can be used to simulate regional climate change in response to increasing GHG concentrations: General Circulation Models (GCM) and Regional Climate Models (RCM). The resolution adopted by GCM (about 100 km) is not sufficient to adequatly capture the orographic feature of this complex area. On the other side, RCMs provide an increase in resolution and can capture physical processes and feedbacks occurring at regional or local scales that GCMs are not able to describe (Anav et al., 2010 [1]). A number of regional climate model (RCM) systems have been developed during the last years in order to downscale the output of large scale global climate model simulations and produce fine scale regional climate change information useful for impact assessment and adaptation studies. Today multi-decadal-to-centennial simulations at grid spacing of a few tens of km or even less have become feasible. The generation of climate scenarios at high spatial resolution is needed (Giorgi, 2006 [6]) to support impact studies about adaptation strategies to climate change, The aim of this paper is to evaluate the ability of the regional climate model CCLM 4.8 (COSMO model in Climate Mode, version 4.8) to simulate the climate of the past in the Mediterranean area at a spatial resolution of 14 km. This is an efficient way to test the performance of a classical dynamical downscaling approach in producing high resolution climatic scenarios over a complex topography area. The innovation of this work is the use of a non-hydrostatic regional climate model (COSMO-CLM) to perform climatological runs. The non-hydrostatic modelling allows providing a good description of the convective phenomena (Holton2004), which are generated by vertical movement (through transport and turbulent mixing) of the properties of the fluid as energy (heat), water vapour and momentum.

The following sections are arranged as follows: section 2 provides a general description of model and observations dataset involved in the analysis; in section 3, results about temperature (3.1) and precipitations (3.2) are represented and compared through trend charts and bias maps; finally, section 4 summarizes the results obtained and makes the conclusions.

2 - MODEL AND DATA

2.1 - THE REGIONAL CLIMATE MODEL COSMO-CLM

At CMCC, the regional climate model COSMO-CLM (Rockel and Geyer, 2008 [11]) is currently used to perform climate simulations: it is the climate version of the COSMO LM model (Steppeler et al., 2003 [15]), which is the operational non-hydrostatic mesoscale weather forecast model developed initially by the German Weather Service and then by the European Consortium COSMO. Successively, the model has been updated by the CLM-Community, in order to develop also a version for climate application (COSMO CLM). The development of COSMO CLM has been driven by two main reasons (Rockel et al., 2008 [12]): the first was the idea of developing one model able to simulate both weather and climate, and the second was the need of introducing a non hydrostatic formulation, in order to have a convection resolving weather simulation. This is a very important topic, due to the difficulty in predicting the effects of this phenomenon, such as sudden high intensity rainfall. COSMO-CLM can be used with a spatial resolution between 1 and 50 km even if the non hydrostatic formulation of the dynamical equations in LM made it eligible especially for the use at horizontal grid resolution lower than 20 km (Böhm et al. 2006 [2]). These values of resolution are usually close to those requested by the impact modellers; in fact these resolutions allow to describe the terrain orography better than the global models, where there is an over- and underestimation of valley and mountain heights, leading to errors in precipitation estimation, as this is closely related to terrain height. Moreover the non-hydrostatic modelling provides a good description of the convective phenomena, which are generated by vertical movement (through transport and turbulent mixing) of the properties of the fluid as energy (heat), water vapour and momentum. Convection can redistribute significant amounts of moisture, heat and mass on small temporal and spatial scales. Furthermore convection can cause severe precipitation events (as thunderstorm or cluster of thunderstorms). Another advantage related to the usage of COSMO CLM, with respect to other climate regional models available, is that the continuous development of LM allows improvements in the code that are also adopted in the climate version, ensuring that the central code is continuously update. The mathematical formulation of COSMO-CLM is made up of the Navier-Stokes equations for a compressible flow. The atmosphere is treated as a multicomponent fluid (made up of dry air, water vapour, liquid and solid water) for which the perfect gas equation holds, and subject to the gravity and to the Coriolis forces. The model includes several parameterizations, in order to keep into account, at least in a statistical manner, several phenomena that take place on unresolved scales, but that have significant effects on the meteorological interest scales (for example, interaction with the orography). The main features of the COSMO CLM simulation are:

- nonhydrostatic, full compressible hydro-thermodynamical equations in advection form;
- base state: hydrostatic, at rest;
- prognostic variables: horizontal and vertical Cartesian wind components, pressure perturbation, temperature, specific humidity, cloud water content. Optionally: cloud ice content, turbulent kinetic energy, specific water content of rain, snow and graupel;
- coordinate system: generalized terrain-following height coordinate with rotated geographical coordinates and user defined grid stretching in the vertical direction. Options for (i) base-state pressure based height coordinate, (ii) Gal-Chen height coordinate and (iii) exponential height coordinate (SLEVE) according to Schär et al. (2002 [14]);
- grid structure - Arakawa C-grid, Lorenz vertical grid staggering;
- time integration: time splitting between fast and slow modes (Leapfrog, Runge-Kutta);
- spatial discretization: 2° order accurate Finite Difference technique;
- parallelization: Domain Decomposition (MPI as message passing S/W);
- parameterizations: Subgrid-Scale Turbulence; Surface Layer Parameterization; Grid-Scale Clouds and Precipitation; Subgrid-Scale Clouds; Moist Convection; Shallow Convection; Radiation; Soil Model; Terrain and Surface Data.

2.2 - SIMULATION SET-UP

The main features of the simulation setup are briefly summarized. The model version used to run the simulation is 4.8 CLM13 and the interpolator INT2LM model version 1.10 CLM2. The simulation has been carried out with boundary conditions provided by the ERA40 Reanalysis (Uppala et al., 2006 [16]), characterized by a horizontal resolution of 1.125. (about 128 km). The horizontal resolution adopted in the simulation, instead, is of 0.0715. (about 8 km). The period considered for the validation analyses in the present work is 1971-2000 and the analysed domain is shown in Fig. 1.

The main features of the simulations are briefly summarized in table 1.

2.3 - OBSERVATIONAL DATASET

The dataset used for 2-metres temperature and precipitation evaluation is E-OBS, an European daily high resolution (0.25° x 0.25°) gridded data set for precipitation, minimum, maximum, and mean surface temperature and sea level pressure for the period 1950-2010. It has been

Table 1
Main features of the COSMO-CLM set-up.

Driving data	ERA40
Horizontal resolution	14 km
Num. of Grid points	385 x 265
Num. of vertical levels in the atm.	40
Num. of soil levels	7
Soil scheme	TERRA-ML
Time step	150 s
Melting processes	yes
Convection scheme	TIEDTKE
Frequency of radiation computation	1 hour
Time integration	Runge-Kutta (3rd ord.)
Frequency update boundary cond.	6 hours

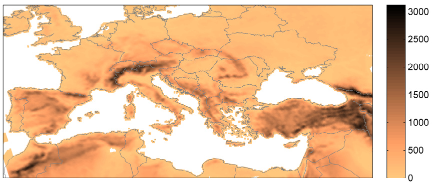


Figure 1:
Orography of the analysed domain.

designed to provide the best estimate of grid box averages rather than point values to enable direct comparison with RCMs (Haylock et al., 2008 [8]).

Concerning the total cloud cover validation, instead, the ERA-Interim Reanalysis (at a resolution of 0.703125°, about 79 km) have been used. The ERA-Interim reanalysis (Dee et al., 2011 [4]) of the global atmosphere cover the period since 1979 and are continuously updated in real time.

3 - VALIDATION

The evaluation of the accuracy of the simulation is performed considering the daily values of 2-metres mean temperature (T_2M) and daily total precipitation (TOT_PREC) for the simulated period 1971-2000. The validation process involves the analysis of seasonal cycle, trend and seasonal means; moreover, daily values of the variables of interest (spatially averaged over the whole domain) have been statistically analysed, calculating the Probability Density Functions (PDF). Finally, model output and observations are compared in each grid-point and their differences are displayed on maps of the entire domain.

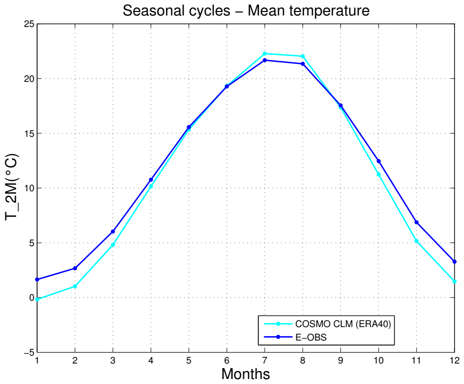


Figure 2:
seasonal cycle of mean temperature: COSMO-CLM output (cyan) and EOBS data (blue)

3.1 - TEMPERATURE

The seasonal cycle (Fig.2) ranging from 0° to 22°C, shows a good match between model and dataset, with a maximum bias of about 2°C in winter. Concerning the statistical characterization, the daily temperature PDF distributions (Fig.3) of model and observations show a faily good agreement, with two peaks reached at about 3°C and 20°C. The model output registers more extreme values in both sides, while E-OBS dataset is characterized by greater density in the middle range. Looking at the annual trend (Fig.4), it is easy to register a general increase over the years, with an underestimation of the model by about 0.5°C for most of the period, increasing up to 1°C in the last 5 years.

The mean temperature maps of the whole area are shown in Figures 5 (a),(c),(e),(g). The bias maps (Fig. 5 (b),(d),(f),(h)) show a general underestimation of the model during the cold seasons (DJF and SON), with highest bias occurring in the Alpine region. In JJA a general hot bias ranging between 2° and 4°C in the eastern part is registered, along with a slight cold bias over Alps and northern Spain. The rest of the year is characterized by a very good agreement on the western regions.

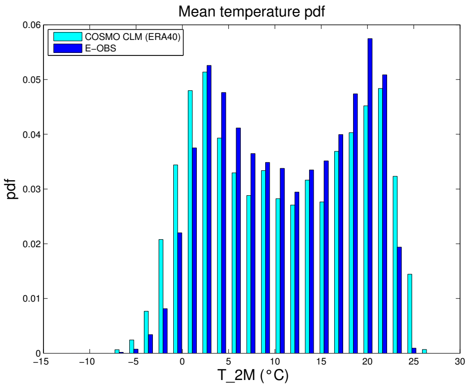


Figure 3:
PDF functions for mean temperature: COSMO-CLM output (cyan) and EOBS data (blue)

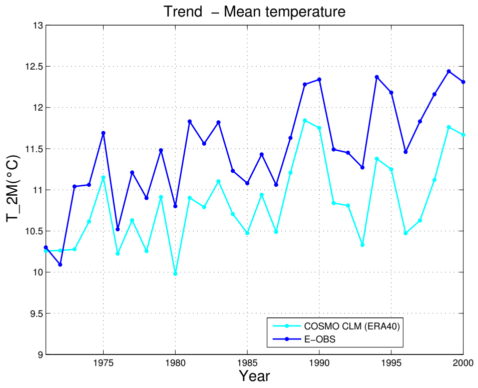
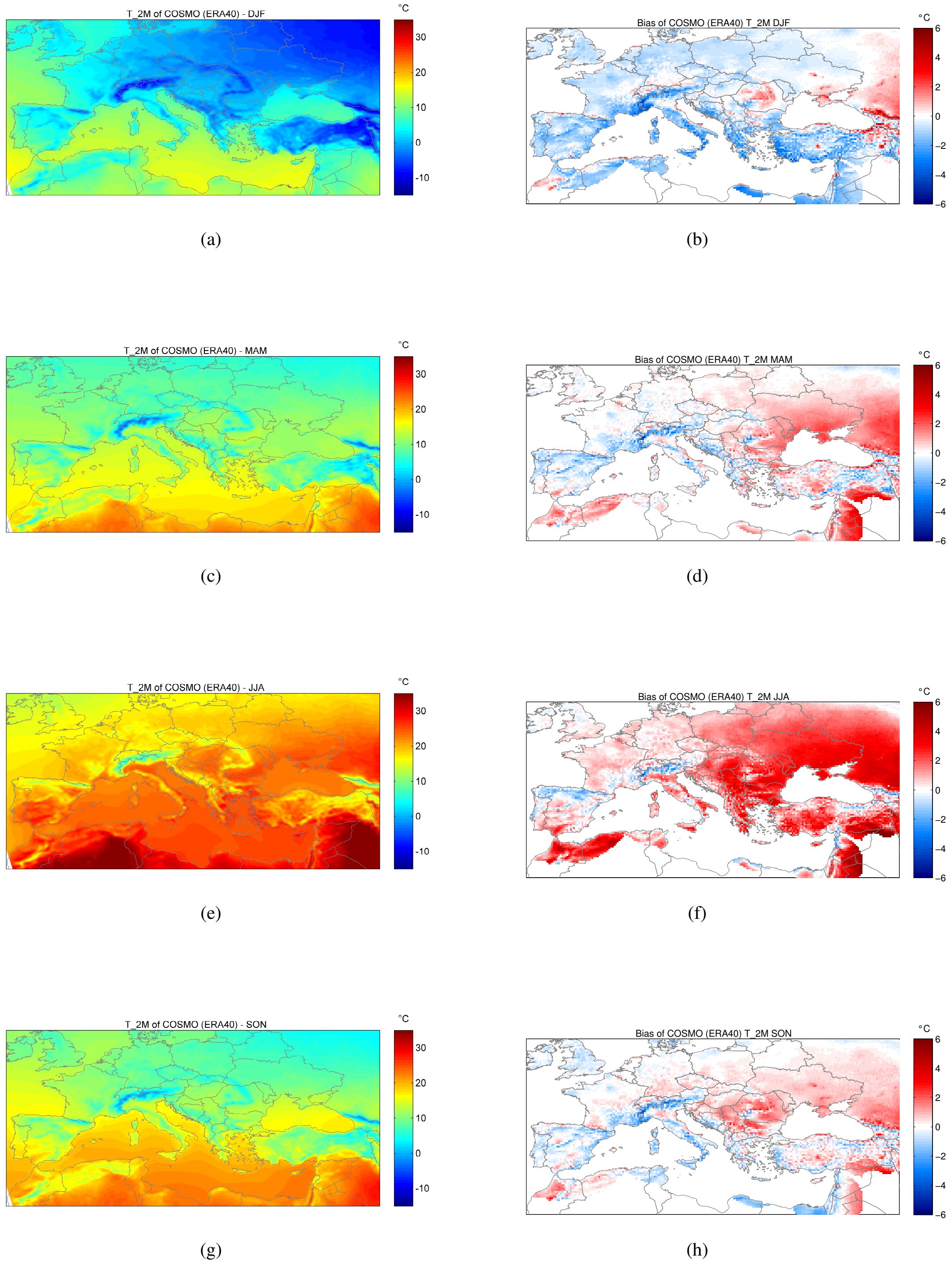


Figure 4:
annual time series of mean temperature: COSMO-CLM output(cyan) and EOBS (blue)



(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure 5:
Seasonal mean temperatures (°C): model output (left column) and bias with respect to E-OBS dataset (right column).

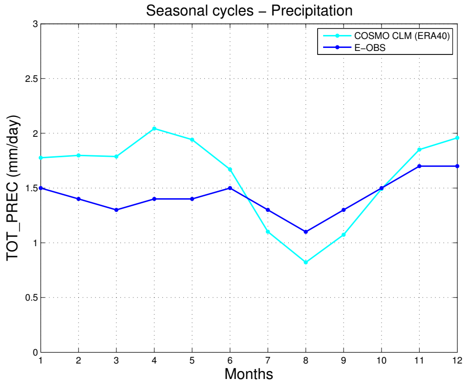


Figure 6:
seasonal cycle of total precipitation: COSMO-CLM output (cyan) and EO-BS data (blue)

3.2 - PRECIPITATION

The seasonal cycle provided by COSMO-CLM is fairly similar to the observed one, but with an overestimation from November to June (Fig.6). Looking at mean daily precipitation PDF (Fig.7), most of the values (both COSMO-CLM and E-OBS) occur between 1 and 2 mm/day, even if observed dataset has more occurrences within this interval. Simulated data have a more rapid increase and slower decay in distribution compared to E-OBS: model results proved to have a higher variance than observations. The annual time series (Fig.8) shows a slightly decreasing trend of COSMO-CLM, while E-OBS has a constant average progression: in this case, ERA40-driven model keeps a regular 2mm-positive shift in the first half and becomes more irregular in the following years, yet its behaviour is generally close to the dataset.

The mean maps (Fig. 9 (a),(c),(e),(g)) show that, according to the model output, precipitations mostly occur in DJF and MAM, with highest values in mountain areas (up to 8 mm/day). In JJA, the only worth-to-notice element is a peak on the Alpine region, while in SON the mean values hardly exceed 5 mm/day. Con-

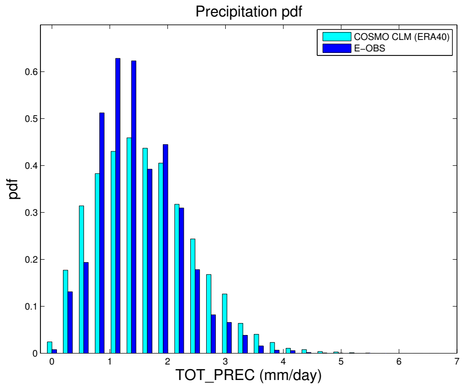


Figure 7:
PDF functions for total precipitation: COSMO-CLM output (cyan) and E-OBS data (blue)

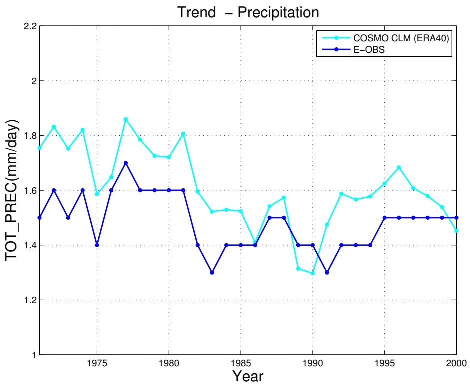


Figure 8:
annual time series of total precipitation: ERA40 driven simulation (cyan) and E-OBS (blue)

cerning the bias analysis (Fig. 9 (b),(d),(f),(h)), the COSMO model tends to overestimate in high orography areas (e.g. Alps and Pyrenees), with significant differences in DJF and MAM (∼4 mm/day); a significant underestimation is observed in Portugal, whereas there is a better match elsewhere; in JJA, the agreement is better, being a general slight underestimation lesser than 1 mm/day, with the exception of Alpine area (strong overestimation).

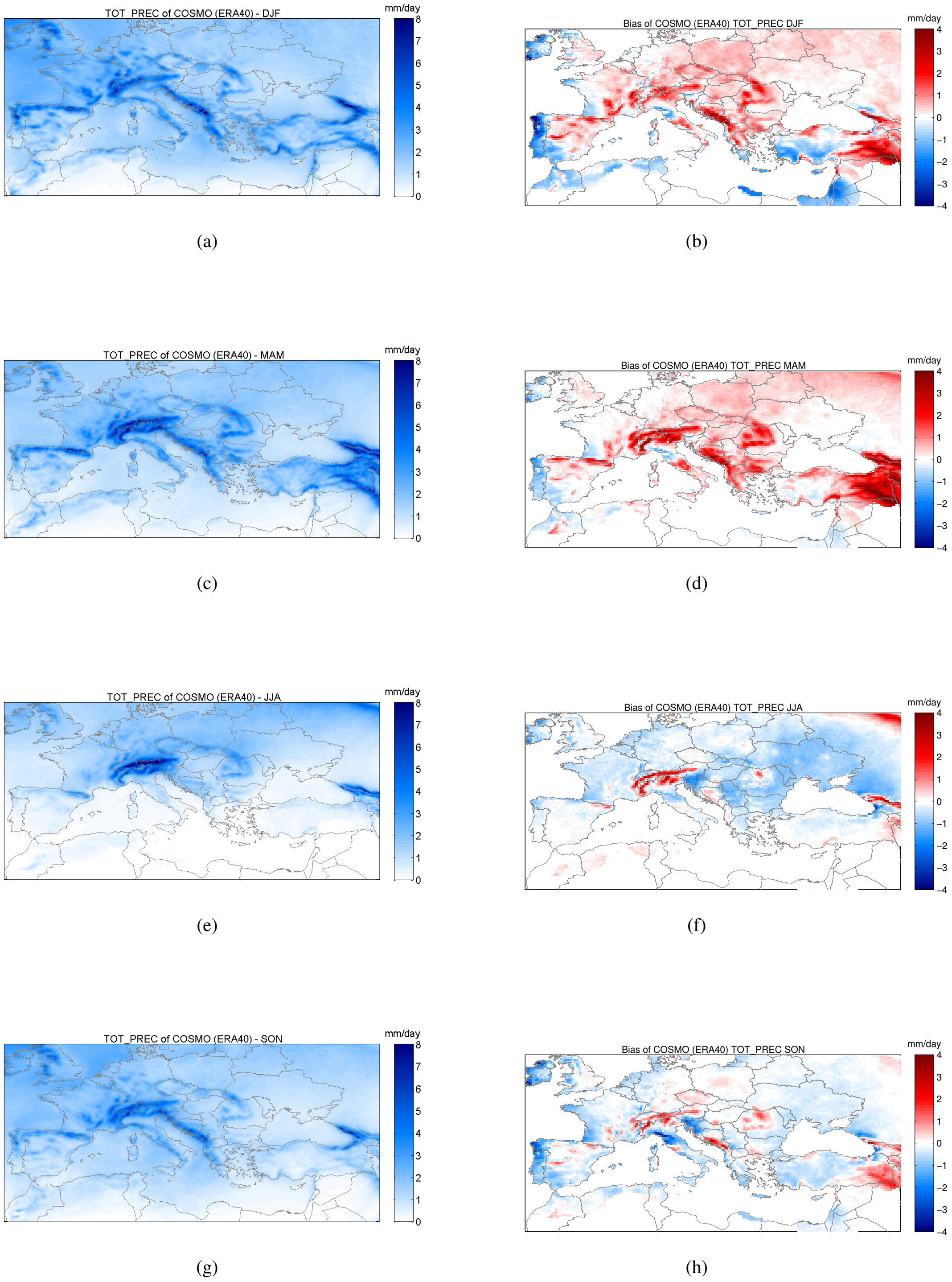


Figure 9:
Seasonal mean daily precipitation (mm/day) for ERA40 driven simulation and their bias with respect to E-OBS dataset.

3.3 - TOTAL CLOUD COVER

Since the total cloud cover is not present in the E-OBS dataset, the ERA-Interim Reanalysis have been used to perform the validation of this variable. Moreover, being the analyzed simulation driven by the ERA40 Reanalysis, it is to interest also compare the total cloud cover of the COSMO-CLM output with the ERA40 themselves.

Several authors have already performed a comparison between the results of regional climate models respectively driven by ERA-Interim or ERA40, such as Cardoso et al.(2012)[3], in which they calculated error statistics on the precipitation in the Iberian peninsula, or Roesch et al. (2008)[13] focused on the 2-meters mean temperature and Jaeger et al. (2008)[9] who used the ERA15 and ERA40 data as observational dataset.

According to the ERA-Interim availability, the time period investigated to perform the total cloud cover analysis is 1979-2000. Concerning the comparison between ERA-Interim and COSMO-CLM, the RCM output has been interpolated onto the grid of ERA-Interim, whereas for what concerns the comparison between ERA40 and COSMO-CLM, and between ERA40 and ERA-Interim, all the data have been interpolated onto the grid of ERA40 (1.125°, about 128 km).

First, analyzing the difference between COSMO-CLM and ERA-Interim (first column of Fig. 10), there is a general overestimation of the total could cover, more evident in the summer season, with a peak of about 20% on the north-west Africa. Only on the north-east Europe in winter and on the north coast of Turkey and Israel in summer, an opposite trend is found. In winter and autumn, a good agreement is shown, especially in the northern Europe. More in detail, in winter the overestimation on the Mediterranean sea is especially due to the forcing; in fact, the ERA40 Reanalysis overestimates the total cloud cover with respect to the ERA-Interim (third column of Fig. 10). This trend is evident also in autumn, in which, instead, there is an overestimation in the northern Africa, which is totally due to the regional model.

In spring and summer, COSMO-CLM tends to exacerbate the overestimation already present in the ERA40 data, as shown in the comparison between ERA40 and ERA-Interim (third column of Fig. 10), simulating higher cloud cover with respect to its forcing (second column of Fig. 10). This explains the higher values of overestimation, displayed in the first column of Fig. 10. The summer underestimation in Turkey and in Israel can be totally attributed to the regional model; in fact, this pattern is not present in the comparison between ERA40 and ERA-Interim, but it is only present in the comparison between model and its forcing.

In conclusion, COSMO-CLM generally tends to overestimate the total cloud cover, but this overestimation can be partly attributed to the forcing, especially in some seasons and regions.

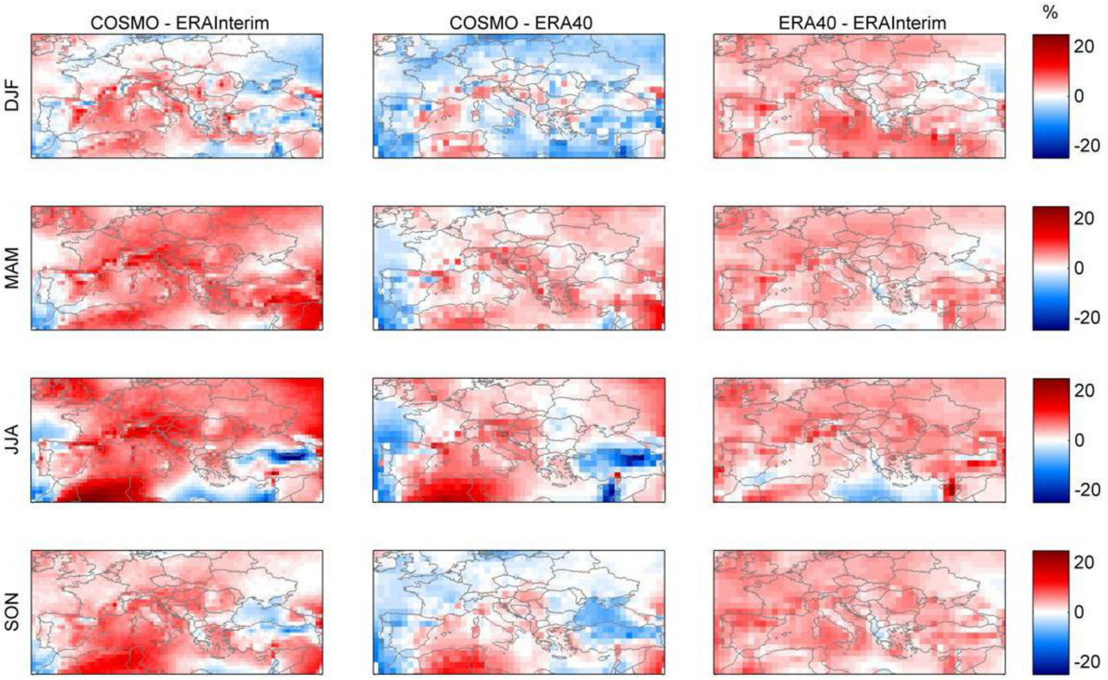


Figure 10:
Seasonal total cloud cover differences (%): COSMO-CLM minus ERA-Interim (first column); COSMO-CLM minus ERA40 (second column); ERA40 minus ERA-Interim (third column). Time period of investigation: 1979-2000.

4 - CONCLUSIONS

In this research work, we have presented an analysis of a RCM simulation over the Mediterranena region at the spatial resolution of 14 km. The non-hydrostatic RCM COSMO-CLM has been adopted to simulate a thirty years period (1971 - 2000), using boundary conditions provided by ECMWF ERA40 Reanalysis. The model response has been analysed in terms of 2-meter temperature and precipitation, and a comparison with available observations has been carried out. In order to give a full and exhaustive representation of the model output, all the data a belonging to the time interval considered have undergone a temporal analysis (seasonal cycles, annual trends), statistical (PDF) and spatial (model and bias maps). The results obtained in this process prove an overall good capability of the Regional Climate Model COSMO-CLM in simulating the main features of the observed climate over the wide area of Mediterranean Sea: the domain values of the simulated 2-m mean temperature display a very good agreement with observations. Seasonal cycles, distributions and annual trends are well captured, especially for temperature, while precipitations feature a slightly more erratic behaviour. The bias, as shown on the maps, is always heavier on high orography zones, as the model gives colder temperatures and more intense rainfalls in these points.

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